

# Reply to “are GRB 090423-like bursts from the superconducting cosmic strings?”

PACS numbers:

Cusps of superconducting cosmic strings were first suggested in [1] as central engines driving gamma-ray bursts (GRBs). A more elaborate description can be found in [2]. In the framework of such a cosmic string GRB (CSGRB) model, recently we have shown that some high redshift GRBs (e.g., GRBs 080913 and 090423) can be well accounted for in the aspects of their luminosities, durations, as well as their inferred star formation rates [3]. In our calculations, an important angle as  $\theta \sim 1/\gamma \sim 10^{-3}$  is invoked, where  $\gamma$  is the Lorentz factor of the string segment that is responsible for the GRB prompt emission. However, in the Comment [4] Wang, Fan, & Wei claim that such a very small angle could be in contradiction with the opening angle of the GRB outflow as  $\theta_{\text{GRB}} \sim 0.2$ , which is inferred from the GRB afterglow observations [5]. Although it is a very good attempt to find more constraints on the CSGRB model from afterglow emission, it still needs to be noticed that *the angle  $\theta$  actually is not the opening angle of the GRB outflow, but is just the collimation angle of the radiation of the corresponding string segment*. In fact, the CSGRB model never requires that the opening angle should be as small as  $10^{-3}$ . As shown in Figure 1, the GRB outflow could instead be very wide, since all parts of the string near the cusp can generate electromagnetic (EM) wave radiation.

In more details, since the part farther from the cusp has smaller Lorentz factor (and thus larger radiation collimation angle), the released EM wave energy per unit solid angle should decrease with increasing viewing angle (the angle between the line of sight and the direction of the string velocity at cusp) as [6]

$$\frac{dE_{\text{em}}}{d\Omega} = \begin{cases} kI_0^2 l / (c^2 \theta^3), & \text{for } \theta > \theta_{\min} \\ kI_0^2 l / (c^2 \theta_{\min}^3), & \text{for } \theta \leq \theta_{\min} \end{cases} \quad (1)$$

where  $\theta_{\min} \sim 10^{-8} \alpha_{-8} B_{0,-7} f_z^{1/2}$  can be determined by the equation  $P_{\max} \sim I_{\max}^2 / c \sim \mu l c^2 / T_i$ . Due to the low frequencies of the EM waves, the released energy would be absorbed by the surrounding medium and thus a relativistic GRB outflow is produced. *In view of the string-like structure of the central engine, the structure of the GRB outflow is likely to be an arc rather than a usually-considered spherical cap*. The arc can be considered to be consisted by a series of ‘bullets’, all of which have the similar direction of motion, as illustrated in Figure 1. The bullets can be described by an initial Lorentz factor  $\gamma_i$  and energy  $E_b = \gamma_i k I_0^2 l / c^2$ , where we assume that the Lorentz factor of a bullet is same to the Lorentz factor of the corresponding portion of the string, which is a basic

assumption in the CSGRB model.

Then a more interesting question arises as whether the particular CSGRB outflow produces the observed afterglow emission. For a single bullet, its sideways expansion could be insignificant, since its adjacent bullets have

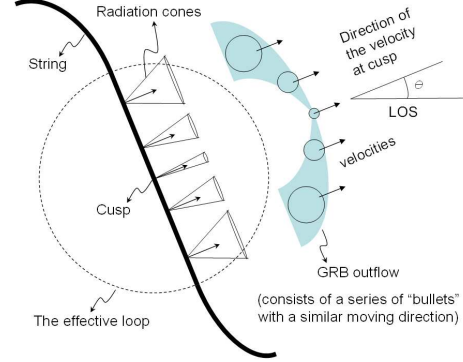


FIG. 1: A schematic cartoon for the CSGRB model.

the same motion direction. Denoting the cross section of the bullet by  $\mathcal{S}$ , the dynamic evolution of the bullet can be determined by the equation  $E_b = \gamma^2 \mathcal{S} n_1 m_p c^2$ , where  $\mathcal{L} = 2\gamma^2 ct$  is displacement of the bullet and  $t$  is the observer’s time. Consequently, we can obtain  $\gamma = (E_b / 2\mathcal{S} n_1 m_p c^3 t)^{1/4} \propto t^{-1/4}$ . In such a case, the afterglow emission can be roughly estimated to be  $F \propto (\epsilon_e E_b / t) \theta_{\text{rad}}^{-2} \sim \epsilon_e \gamma^2 E_b / t \propto t^{-1.5}$ , where  $\epsilon_e$  is the electron energy equipartition factor. On the other hand, as the deceleration of the bullets, the later afterglow emission will be contributed by more bullets with larger initial Lorentz factor (and thus more energy). If these bullets are obviously separated, we may see a series of re-brightenings in the afterglow light curves, as argued in [4]. However, the outflow actually is continuous. So, instead of the re-brightenings, a smooth afterglow light curve can be obtained, which is probably much flatter than  $t^{-1.5}$ . Such a result in principle do not contradict with the afterglow observation for GRB 090423 [5]. Of course, a more detailed calculation and a fitting to the observations may provide much more solid arguments.

K. S. Cheng, Y. W. Yu, and T. Harko  
Department of Physics, The University of Hong Kong,  
Pokfulam Road, Hong Kong, China

[1] A. Babul, B. Paczynski, and D. Spergel, *Astrophys. J.* **316**, L49 (1987); B. Paczynski, *Astrophys. J.* **335**, 525

(1988).

- [2] V. Berezhinsky, B. Hnatyk, and A. Vilenkin, Phys. Rev. **D64**, 043004 (2001); V. Berezhinsky, B. Hnatyk, and A. Vilenkin, Baltic Astronomy **13**, 289 (2004)
- [3] K. S. Cheng, Y. W. Yu, & T. Harko, Phys. Rev. Lett. **104**, 241102 (2010)
- [4] Y. Wang, Y. Z. Fan, & D. M. Wei, preceding Comment, Phys. Rev. Lett.
- [5] P. Chandra et al. ApJ, **712**, L31 (2010)
- [6] E. M. Chudnovsky, G. B. Field, D. N. Spergel, and A. Vilenkin, Phys. Rev. **D34**, 944 (1986); A. Vilenkin and T. Vachaspati, Phys. Rev. Lett. **58**, 1041 (1987)